Seasonal CO₂ and CH₄ Emissions from Termite Mounds in the Sub-Sahelian Area of Burkina Faso

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Abstract: CO₂ and CH₄ emissions from termites based on in situ measurements are less documented than laboratory-based studies. Few data associated biotic and abiotic factors in ecological conditions to assess greenhouse gases emissions. The present study aims to quantify CO₂ and CH₄ emissions from Macrotermes bellicosus mounds during 12 months in a natural reserve of Ouagadougou, Burkina Faso. The CO₂ emission was significantly related to season, mound temperature, rainfall and relative humidity. During the wet season, high CO₂ emission rates were found (229-964 mg CO₂ m⁻² h⁻¹) compared to the dry season (58-261 mg CO₂ m⁻² h⁻¹). Furthermore, high CO₂ emissions were noted for mound temperature < 30°C, rainfall > 47 mm and moisture > 65%. A rate of 15 µg CH₄ m⁻² h⁻¹ was recorded during the first rain season in 2010 against a quasi-undetectable amount during the second rain season in 2011. This study emphasizes that most environmental parameters have a particular effect on CO₂ and CH₄ emissions from the termite mound species. It will also be necessary to investigate the diversity, distribution and spatiotemporal evolution of microbial community located in termite guts and mounds which are the relevant biotic factors involved in gas production and emission.

Keywords: Carbon dioxide • Methane • Macrotermes bellicosus mounds • Season • Temperature • Moisture

INTRODUCTION

Methane (CH₄) and carbon dioxide (CO₂) are two powerful greenhouse gases (GHG) more released in the atmosphere. CH₄ has a global warming potential 25 times than that of CO₂ on a 100-years time horizon [1]. Globally, more than 580 Tg CH₄ are released annually in the atmosphere, with over 70-80% from biological sources [2]. 2/3 CH₄ emissions originate from anthropogenic sources as fossil fuel energy production and use, paddy rice cultivation, enteric fermentation in the guts of ruminant animals, biomass burning, land-use changes, animal waste and sewage and 1/3 comes from natural sources including wetlands, CH₄ hydrates, oceans, fresh water and termites [3].

The last-mentioned (termites) are widespread in tropical areas and occur between 45°N and 45°S, or approximately two-third of the earth’s land surface [4]. Termites are an integral component in tropical ecosystems by cycling organic matter, fertilizing soil and maintaining soil structure. However, harboring a dense and different microbial community in their gut, termites produce CH₄ and CO₂ during organic matter digestion [5]. Numerous studies have shown the contribution of termites to magnitude of 3-56% of the global budget of CH₄ emissions [6-10]. However, these studies did not include biotic and abiotic factors to assess these contributions. The lack of measured emission rates from termite mound and representative field experiments including climatic factors could induce assessment errors and uncertainties. More recently, Sugimoto et al. [11] and Brümmer et al. [12] revealed 0.2-2.0% CO₂ and 0.15% CH₄ in termite contribution to global terrestrial emissions, respectively.

The sub-sahelian savanna of Burkina Faso, in West Africa, with high temperature and rainfall allows studying C trace emissions from termite mounds.
The present study aims to investigate on seasonal CO₂ and CH₄ emissions from termite mounds using a fully replicated field experimental design. The main objectives were to quantify (1) CO₂ and CH₄ release from termite mounds, (2) determine the impact of temperature, precipitation and humidity on CO₂ and CH₄ release and (3) highlight season effect on the mentioned gas emissions.

MATERIALS AND METHODS

Experimental Site: The study site is localized in the natural reserve of Somgandé (12° 24' N, 1° 29' W and altitude 294 m) in Ouagadougou, in centre of Burkina Faso. It extends on a surface of 15 hectare (ha) where agricultural activities are carried out in rainy season. The study on the evaluation of CO₂ and CH₄ emissions was performed from August 2010 to August 2011 from *Macrotermes bellicosus* termite mounds.

CH₄ and CO₂ Emission Measurements from Termite Mounds: CH₄ and CO₂ emission measurements from *Macrotermes bellicosus* termite mounds (n=2) were recorded on monthly basis from August 2010 to August 2011 (except December, 2010). All measurements were performed between 6-7 h AM where gas emissions were higher than 6-7 h PM ones [Sawadogo et al. submitted]. Mounds were of approximately the same size, with an average diameter of 2 m and a height from 0.65 to 1.17 m. They are distant of 393 m. CH₄ and CO₂ emissions from the mounds were measured in situ by using static manual chambers of the same volume (8 cm diameter, 21 cm length) made from polyvinylchloride (PVC) fitted septum for headspace gas sampling. Static chambers (n=3) were installed to a depth < 20 cm into each mound, randomly, in order to reach main galleries from which gases are freely released and stored in the chamber headspace.

Headspace gas samples (10 ml) were withdrawn with 10 ml graduated pressure lock syringes. On each 10 ml gas sample, only 4 ml were immediately transferred into 4 ml vacutainer tube (Improvacuter). These tubes were transported to Laboratory for CH₄ and CO₂ analysis with a gas chromatograph (Girdel serie 30 cathometer) equipped with a manual injector, a 80/100 Porapak Q (for CH₄ analysis) and 100/120 Porapak Q (for CO₂ analysis) columns assembled in parallel and connected to a thermal conductivity detector (TCD) and a potentiometric recorder (SERVOTRACE type Sefram Paris, 1 mV). The analysis conditions were: injector temperature (90°C), oven (60°C), detector (100°C). H₂ was the carrier gas and reference gases (CH₄ and CO₂) were supplied by Burkina Industrial Gas and used as standards for determining linear regression as described by Sawadogo et al. [13]. In total, 106 gas samples were collected during this study period with a sampling frequency of once to twice per month from each termite mound.

Auxiliary Environmental Measurements: During gas sampling, mound temperature (Tₘₐₜ) was measured immediately close to each static chamber using a field Bioblock Scientific Minitherm 16228 thermometer fitted stainless steel temperature probe length of 10 cm with an accuracy of ±1°C. Without touching mound wall, the probe was inserted 10 cm into mounds throughout a hole made at 20-30 cm depth and 0.7 cm diameter in order to reach small galleries and minimize gas escape. Triplicate of mound temperature were measured on each termite mound at each sampling time. In parallel, the air temperature (Tₐ) was also measured beside termite mound before and after gas sampling. The mean monthly meteorological temperature (Tₐ), rainfall (Rₙ) and relative humidity (RHₙ) were provided by the Somgandé meteorological station (Direction Générale de la Météorologie de Somgandé) located near to our experiment site (~1.1 km).

Data Processing: Microsoft Excel (2007) and SPSS 17.0 were used for graphic representations and data statistical analysis, respectively. One-way analyses of variances (ANOVA) were performed to identify significant differences in means of CO₂ and CH₄ values (n=106) with regard to Tₘₐₜ, Tₐ, Rₙ, RHₙ and seasons. Statistical significance was defined at P<0.05, unless otherwise noted. Least Standardized Difference (LSD) Post Hoc tests were used to identify significantly different CO₂ or CH₄ means among seasonal scales (wet, cold dry and hot dry seasons). Linear regression and Pearson correlation analyses were used to evaluate, respectively, the significance and correlation of relationships between CO₂ or CH₄ emissions and one of the environmental parameters (Tₘₐₜ, Tₐ, Rₙ, RHₙ) with P<0.05.

RESULTS

CO₂ Emissions from Termite Mounds: CO₂ emissions measured at intervals of 15 days per month fluctuated more or less during samplings, generally (Fig. 1). For termite mound 1, the lowest and highest CO₂ emissions were 1923 ppmv recorded on April 15th and 31084 ppmv on July 15th. A similar range of CO₂ emissions (1918 ppmv on April 30th and 44568 ppmv on July 15th) was observed for the termite mound 2.
Fig. 1: Variation of CO$_2$ emissions (n=3, ± SE) from termite mounds during sampling periods in 2010 and 2011

Fig. 2: Variation of monthly CO$_2$ emissions (n=6-12, ± SE) from termite mounds in 2010 and 2011

Fig. 3: Temperature variation inside termite mounds (T$_{mound1}$ and T$_{mound2}$) (n=3, ± SE) and air (T$_{air}$) (n=2) for each sampling period in 2010 and 2011

From both termite mounds, CO$_2$ releases were greater in July than April (Fig. 2). The lowest mean CO$_2$ emissions were 1959 ppmv for termite mound 1 and 2463 ppmv for mound 2 in April. The highest were recorded in July with 28407 and 32235 ppmv for mounds 1 and 2, respectively. Regardless of mound, there was a 13-14 fold difference in CO$_2$ emissions between the measurements of April and July of the same year.

**Mound and Environmental Temperatures:** In general, the termite mound temperatures (T$_{mound1}$ and T$_{mound2}$) were slightly high as compared to air temperature (T$_{air}$) during the sampling periods (Fig. 3). The low air temperatures ranged from 18.2 to 22.8°C between January 15$^{th}$ and February 28$^{th}$ 2011 and maximum air temperatures from 27.5 to 30.2°C between 15$^{th}$ March and 15 May 2011. The temperatures of both termite mounds were not significantly different ($P=0.64$), but varied slightly from 24.2°C (August 16$^{th}$) to 32.6°C (April 30$^{th}$) compared to air temperature (18.2°C on January 15$^{th}$ to 30°C on April 30$^{th}$ and May 15$^{th}$) during the experiment period. T$_{air}$, T$_{mound}$ and meteorological ambient temperature (T$_{m}$) moved in the same order and were very significantly different from each other (Table 1).
Table 1: Relationships between temperature of termite mound (\(T_{mound}\)), air temperature (\(T_{air}\)) and meteorological temperature (\(T_{m}\)).

<table>
<thead>
<tr>
<th>Variable</th>
<th>(R^2)</th>
<th>(r)</th>
<th>(P) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(T_{mound}) x (T_{air})</td>
<td>0.478</td>
<td>0.691</td>
<td>0.006</td>
</tr>
<tr>
<td>(T_{mound}) x (T_m)</td>
<td>0.673</td>
<td>0.820</td>
<td>0.001</td>
</tr>
<tr>
<td>(T_{air}) x (T_m)</td>
<td>0.795</td>
<td>0.892</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Table 2: Variations in termite mound CO\(_2\) emissions between wet season (WS: June-October), cold-dry season (CDS: November-February) and hot-dry season (HDS: March-May). Values are difference of mean CO\(_2\) emissions \(\pm\) SE between both seasons.

<table>
<thead>
<tr>
<th>Interaction of factors</th>
<th>Difference of mean CO(_2) emissions (ppmv)</th>
<th>(P) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>WS x CDS</td>
<td>13172±1754</td>
<td>0.000</td>
</tr>
<tr>
<td>WS x HDS</td>
<td>17174±1498</td>
<td>0.000</td>
</tr>
<tr>
<td>CDS x HDS</td>
<td>4001±1878</td>
<td>0.036</td>
</tr>
</tbody>
</table>

Table 3: Relationships between environmental parameters (\(T_{mound}\), \(T_{air}\), \(T_m\), \(R_m\) and RH\(_m\)) and CO\(_2\) emissions from termite mound. \(R^2\): Linear regression, \(r\): Pearson correlation.

<table>
<thead>
<tr>
<th>Variable</th>
<th>(P) value</th>
<th>(R^2)</th>
<th>(r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(T_{mound})</td>
<td>0.000</td>
<td>0.318</td>
<td>-0.564</td>
</tr>
<tr>
<td>(T_{air})</td>
<td>0.169</td>
<td>0.049</td>
<td>-0.222</td>
</tr>
<tr>
<td>(T_m)</td>
<td>0.100</td>
<td>0.174</td>
<td>-0.418</td>
</tr>
<tr>
<td>(R_m)</td>
<td>0.000</td>
<td>0.806</td>
<td>0.898</td>
</tr>
<tr>
<td>RH(_m)</td>
<td>0.012</td>
<td>0.449</td>
<td>0.670</td>
</tr>
</tbody>
</table>

Seasonal CO\(_2\) Emission Variation: CO\(_2\) emitted from Mound 1 and Mound 2 showed a non-significant difference \((P=0.087, \text{data not published})\) along seasons. The average monthly CO\(_2\) emissions from both termite mounds were more important from August to October 2010 and June to August 2011 with ranges of 7710-16766 ppmv and 17018-32235 ppmv, respectively (Fig. 4a). Moreover, low values (1959-8746 ppmv) were recorded from November 2010 to May 2011. These variations followed seasonal changes. Indeed, in all mounds, the difference of mean CO\(_2\) emissions between the wet season (June to October) and the dry season (November to May) was highly significant (Table 2). Likewise within the dry season, a significant difference between the cold-dry season (November-February) and the hot-dry season (March-May) was noted (Table 2). Mean CO\(_2\) emissions ranged from 17794 ppmv (wet season) to 4818 ppmv (dry season). The seasonal variations were related to temperature, rainfall and humidity variations which could affect the CO\(_2\) release from the termite mounds.

For both wet and dry season, CO\(_2\) emissions were negatively correlated with \(T_{mound}\), \(T_{air}\) and \(T_m\) \((r = -0.564, -0.222 \text{ and } -0.418, \text{respectively})\) (Fig. 4a, 4b, 4c; Table 3). However, the relationships between CO\(_2\) release and \(T_{mound}\) was highly significant than that with \(T_{air}\) and \(T_m\) (Table 3).

Although in the dry season (November-May) the temperature ranges were near to those in the wet season (June-October), the CO\(_2\) productions in the dry season were lower than those in the wet season.

The rainfall \((R_m)\) could influence the gravimetric water content of termite mound wall that was not measured during this study. \(R_m\) also differed with regard to different seasons. It varied from 0 (November to February), 0.8 to 33.9 mm (March to May) in the dry season, in contrast to the wet season with a variation of 47.2-378 mm (Fig. 4b). High CO\(_2\) emissions (>7710 ppmv) were recorded for \(R_m\) values >47.2 mm with a maximum in July (28407 and 32235 ppmv for mound 1 and mound 2, respectively), under a \(R_m\) of 378 mm (Fig. 4a, 4b). The relationship between CO\(_2\) emissions and rainfall were strongly correlated in wet season \((r=0.898)\) (Table 3). However, CO\(_2\) emissions were relatively important in cold-dry season (November-February, 0 mm) than in hot-dry season (March-May, up to 33.9 mm) (Fig. 4a, 4b). The rainfall could not alone explain CO\(_2\) emissions observed in dry season, but influence the level of humidity in atmosphere during gas release.

The variations of ambient relative humidity (RH\(_m\)) and CO\(_2\) emission are shown on Figures 4a and 4c. The dependency of CO\(_2\) emissions on seasons (dry and wet) was comparable to that on relative humidity. A 25-54% and 65-78% RH\(_m\) were recorded in the dry season and wet season, respectively. The relationship between CO\(_2\) release and RH\(_m\) could be well described by linear regression \((r = 0.670; \text{Table 3})\).

Seasonal Mound CH\(_4\) Emission: During all the experiment period, CH\(_4\) emitted from both mounds was poorly recorded. The mound CH\(_4\) amounts were just detectable at the threshold of 0.5 ppmv for the wet season time (August to October) and only at the beginning of dry season (November) in 2010. From January to August 2011, CH\(_4\) measurements were low to the detection threshold (<0.5 ppmv). The CH\(_4\) emission did not clearly follow the variation of temperature (\(T_{mound}\) or \(T_{air}\)), rainfall, ambient relative humidity and season, as the case of mound CO\(_2\) emission.

**DISCUSSION**

Impact of Seasonal Variations on Mound CO\(_2\) Emissions: In this study, the field based-experiment results revealed strongly environmental drivers as the main factors causing a significant seasonal variation in mound CO\(_2\) emissions.
Fig. 4: Seasonal CO₂ emissions from termite mounds and related environmental parameters. Monthly means of mound CO₂ emission (n=6-12 ± SE), mound temperature (Tₘ₁ and Tₘ₂, n=6-12 ± SE), air temperature (Tₐ, n=2-4). Climate data [meteorological temperature (Tₐ), rainfall (Rₐ) and relative humidity (RHₐ)] were obtained thanks to the Somgandé meteorological station (Direction Générale de la Météorologie de Somgandé).

Table 4: Mean CO₂ and CH₄ emission rates from *M. bellicosus* termite mounds during wet and dry seasons. Published data from other termite species are given for comparison.

<table>
<thead>
<tr>
<th>Termite mound species</th>
<th>Wet season CO₂ emissions (mg CO₂ m⁻² h⁻¹)</th>
<th>Dry season CO₂ emissions (mg CO₂ m⁻² h⁻¹)</th>
<th>Wet season CH₄ emissions (µg CH₄ m⁻² h⁻¹)</th>
<th>Dry season CH₄ emissions (µg CH₄ m⁻² h⁻¹)</th>
<th>Localization</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Macrotermes bellicosus</em></td>
<td>229-964</td>
<td>58-261</td>
<td>15</td>
<td>(-)</td>
<td>Somgandé natural reserve (Burkina Faso, BF)</td>
<td>This study</td>
</tr>
<tr>
<td><em>Cubitermes fungifaber</em></td>
<td>300-700</td>
<td>100-200</td>
<td>3000-5300</td>
<td>883-2800</td>
<td>Bontiole natural reserve (BF)</td>
<td>[12]</td>
</tr>
<tr>
<td><em>Microcerotermes nervosus</em></td>
<td>nd</td>
<td>nd</td>
<td>4444</td>
<td>558</td>
<td>Tropical Ecosystem Research Center (Australia)</td>
<td>[14]</td>
</tr>
<tr>
<td><em>Tumulitermes Pastinator</em></td>
<td>nd</td>
<td>nd</td>
<td>8475</td>
<td>956</td>
<td>Charles Darwin National Park (Australia)</td>
<td>[14]</td>
</tr>
<tr>
<td><em>M. Bellicosus</em></td>
<td>269-329</td>
<td>59-120</td>
<td>nd</td>
<td>nd</td>
<td>Comoé national park, (Ivory Coast)</td>
<td>[15]</td>
</tr>
</tbody>
</table>

nd: not determined; (-): CH₄ not detected

Termite mound temperature (Tₘ) had a higher significant effect than that of air (Tₐ, P=0.169) and meteorological (Tₐ, P=0.100) temperatures on mound CO₂ emissions. Tₐ and Tₘ are assumed to have an indirect effect on CO₂ emissions by acting near enough on Tₘ. Microclimate maintaining within mounds could result in termite activities with regard to external climate. Indeed, Korb and Linsenmair [15, 16] demonstrated a mound
building by *M. bellicosus* termites and lowest CO$_2$ emission from mounds exposed in rising ambient temperature. These results are in agreement with our data which also revealed a decrease in CO$_2$ emission when temperature increased, especially during the hottest period (March-May). We also observed that this period was correlated with mound architecture construction by the selected species of termite and others. The variation of temperature inside and outside the mounds seems to create changes of internal gas flux and mound structure [15; Sawadogo et al. submitted]. Moreover, Brümmer et al. [12] reported that the lowest CO$_2$ values from *Cubitermes fungifaber* mounds were important at termite mound temperatures $>$32°C. Although our termite species was different, the CO$_2$ emissions recorded from both *M. bellicosus* termite mounds at mound temperatures $>$30°C (in April) were also the lowest (1920-3000 ppmv). Contrasting these results, Ruelle [17] showed that CO$_2$ emission from *Coptotermes lacteus* termite mounds was more important when the mound temperature increased. This termite species (wood-feeding termites) belonging to Rhinotermitidae family does not perform the same activities of *M. bellicosus* (fungus-feeding termites) of Termitidae family. We can also assume that the recent rising trend of atmospheric greenhouse gas concentration with an increase in temperature might lead to changes in the metabolism and activities of termites allowing them to develop strategies of thermoregulation, adaptation and gas exchange according to termite mound [15, 18].

The variation in mound CO$_2$ emission response to temperature across seasons could be attributed to seasonal variations in moisture (rainfall, relative humidity).

Globally, mound CO$_2$ emissions increased with rainfall (47.2 mm $< R_{m} < 378$ mm) and moisture (RH$_m$ > 65-78%) in rainy season. The latter case is in agreement with the findings of Brümmer et al. [12] who found important CO$_2$ emissions at high termite mound moisture values ($>$60%). Moreover, Konaté et al. [19] revealed high CO$_2$ emission rates (432-821 mg CO$_2$ m$^{-2}$ h$^{-1}$) from *Ancistrotermes cavithoras* and *Odontotermes pauperans* termite mounds, in Ivory Coast savanna, with a mean monthly precipitation of 271 during rainy season from July to September. That also strongly supports our findings as these termite species and *M. bellicosus* belong to the Macrotermitinae subfamily. In general, CO$_2$ emissions were greater in wet season than in dry season as described by other studies [12, 15]. The importance of water availability during wet season leads to soil and termite mound moisture favoring food availability, degradation of vegetable organic matter by termites and metabolism of termite mound microorganisms. For instance, greater mound-building activities were observed in rainy season compared to dry season. That could change the inner structure of mound and consequently the CO$_2$ and CH$_4$ fluxes.

**Seasonal Variations in CH$_4$ Emissions:** The CH$_4$ emissions in our study did not follow the trend of CO$_2$ emission for all the considered environmental parameters. The detected CH$_4$ amounts during wet season in 2010 were in accordance with most previous studies data [12, 14, 20] (Table 4). CH$_4$ absence noted during dry season in this study was comparable to low CH$_4$ emission as found by other authors [12, 14, 20] (Table 4). The weak quantification of CH$_4$ emission in wet season in 2011 seems to be related to our designs continually installed under termite construction activity. Nevertheless, this gas absence could be also explained by the oxidation of CH$_4$ by methane-oxidizing bacteria (methanotrophs type I and/or II) suggested and highlighted from mound, desert and other soils where CH$_4$ is present [2, 21-23], particularly in oxic dry lands. Furthermore, a weak foraging activity of termites noted around mound, for the last period, could explain the low CH$_4$ emission rates recorded. Indeed, Sawadogo et al. [13] revealed a variation of CH$_4$ production in 1 L chamber by termites with respect to their food substrates. Some studies underlined at Laboratory scale [9, 24-25] and from field-based experiments [8] a parallel increase of CH$_4$ production with temperature ranging from 19.5°C to 30.5°C. In contrast, Sawadogo et al. [13] and Gomathi et al. [26] pointed out a decrease in CH$_4$ production from *Macrotermes* sp and *M. bellicosus* termite cultures when increasing temperature from 30 to 37°C. As explained above, the important variability of global climate and the real environment conditions can lead these insects to change their physiological mechanism.

In conclusion, our study showed CH$_4$ and CO$_2$ emissions from *Macrotermes bellicosus* termite mounds with regard to the ecosystem conditions of sahelian countries. Globally, CO$_2$ emissions varied significantly between seasons, with mound temperature, rainfall and moisture, whereas CH$_4$ was weakly emitted or undetectable during our experiment campaign. More CO$_2$ release was recorded in wet season, at low mound temperature, high rainfall and relative humidity. That is the first study which really provided monthly CO$_2$ and CH$_4$ emission data allowing observing variations along...
seasons. The data obtained revealed that both gases emission was low at high mound temperature (>30°C), low rainfall (<47 mm) and low moisture (<54%). However, it will be necessary to extend the study over several seasons and years with respect to other termite species and ecological zones of Burkina Faso. Such studies may help to setting strategies for the mitigation of greenhouse emissions and climate change adaptation in sahelian areas.

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3. IPCC, 2001. IPCC range of estimates covers the high and low estimates from a suite of budgets compiled using different approaches listed in the IPCC report.


